ESTCP
Cost and Performance Report

(WP-0122)

Demonstration of the Replacement of the Dyes and Sulfur in the M18 Red and Violet Smoke Grenades

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ACRONYMS AND ABBREVIATIONS

ACSIM	Army Chief of Staff for Installation Management
CAA	Clean Air Act
CAS#	Chemical Abstract System Number
CCB	Configuration Control Board
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
cm	centimeter
CWA	Clean Water Act
DoD	Department of Defense
DoDIC	Department of Defense Identification Code
D&C	Drug and Cosmetic
DPG	Dugway Proving Ground
DSC	differential scanning colorimetry
EA	Environmental Assessment
ECBC	Edgewood Chemical Biological Center
ECP	Engineering Change Proposal
ED&C	External Drug and Cosmetic
EDT	engineering design test
EPA	U.S. Environmental Protection Agency
EPCRA	Emergency Planning and Community Right to Know Act
ESTCP	Environmental Security Technology Certification Program
FDA	U.S. Food and Drug Administration
FD&C	Food, Drug, and Cosmetic
HC	Hexachloroethane
IPT	in-process team
LVOSS	Light Vehicle Obscuration Smoke System
MIL-STD	military standard
MILSPECS	military specifications
mm	millimeter
MMR	Massachusetts Military Reservation
NEPA	National Environmental Policy Act
NSN	national stock number
OB/OD	open burn/open detonation
OEM	original equipment manufacturer
OGI	Oregon Graduate Institute

ACRONYMS AND ABBREVIATIONS (continued)

PBA	Pine Bluff Arsenal
PEL	Production Engineering Laboratory
PM-CCS	Program Manager-Close Combat System
PPA	Pollution Prevention Act
PQT	product quality test
PVT	production validation test
RCRA	Resource Conservation and Recovery Act
sec	second(s)
SOP	standard operating procedure
STANAG	Standardization Agreements (NATO)
SVOCs	semi-volatile organic compound
TA	terephthalic acid
TA/PE	terephthalic acid/pentaerythritol
TDP	technical data package
TSP	total suspended particulates
USACHPPM	U.S. Army Center for Health Promotion and Preventive Medicine
USAEC	U.S. Army Environmental Center
VOC	volatile organic compound

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We gratefully acknowledge the Environmental Security Technology Certification Program (ESTCP) for financial support and encouragement in the effort to replace the sulfur, dyes and other parts of the red and violet colored smoke grenades used by the Pine Bluff Arsenal (PBA).

The authors would like to thank the following personnel for their time and effort in preparing, demonstrating, collecting data, writing reports, and reviewing the information collected for validity and accuracy:

- USAEC
- PBA
- ECBC
- USACHPPM

We also want to acknowledge that this program is just the beginning. The efforts put forth by the Smoke and Dye In-Process Team (IPT) created by the Program Manager-Close Combat System (PM-CCS) have been instrumental in furthering this program. The Smoke and Dye IPT and their respective members have provided many of the valuable tips and information used in this report. The accomplishments of this project would not have been possible without the enthusiasm and support of these individuals and their respective organizations. PM-CCS was provided a copy of this report for their review and comments but has not provided any official comments.

Technical material contained in this report has been approved for public release.

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1.0 EXECUTIVE SUMMARY

1.1 BACKGROUND

In September 1997, the Chief of Staff of the Army directed the Army Chief of Staff for Installation Management (ACSIM) to establish a General Officer Steering committee to address the implications of the restrictions on operations at Massachusetts Military Reservation (MMR). The ACSIM directed and funded the U.S. Army Environmental Center (USAEC) to gather emissions data. The USAEC has developed a comprehensive program to identify the emissions resulting from range operations that involve weapons firing, smoke and pyrotechnic devices, and exploding ordnance, and to assess the environmental and health hazard impacts resulting from their use. In the execution of the program, it has identified four items (two of the colored smoke grenades, one white smoke grenade and one of the smoke pots) that contain and emit toxic and carcinogenic compounds in significant quantities. These smokes and dyes may present a risk to soldiers, to nearby receptors, and to production and test personnel, especially in the hexachloroethane (HC) filled grenades. It is in the best interest of the Army and Department of Defense (DoD) to demonstrate and implement a material substitution for the dyes, smokes, fills and starter patches in these specific munition items. Several alternative materials have been identified. Under this project, the functional and operational capabilities of these items with the alternative (less toxic) dye and smoke materials will be validated prior to their implementation. Replacement has been implemented in other colored grenades but due to excessive flaring and inadequate burn rates, replacement has not occurred in the grenades to be changed under this project (red and violet M18 grenades).

1.2 OBJECTIVES OF THE DEMONSTRATION

The objective of this demonstration was to validate alternative materials and products so that they may be written into new military specifications (MILSPECS), including modified formulations of the smoke grenades to be used in manufacturing. The proposed effort provided production and testing of four potential material substitutions for two smoke munitions items that are considered essential to Army training operations. The potential material replacements included (1) replacing the dye in M18 red grenades, (2) replacing the dye in the M18 violet grenades, (3) an evaluation of the starter patches for use in the colored smoke grenades, and (4) replacing sulfur with a sugar-chlorate formulation. The production of the replacement for HC was not part of the Detailed Demonstration Plan for this project, but the success of the starter mixtures and patches will ensure future technical success of replacement efforts for HC mixtures in the munitions currently containing HC. Demonstration of this program will introduce safer smoke munitions for the soldiers in training and active service. This demonstration included the survey, testing and manufacturing of test, pilot and production runs of these munitions (red and violet smoke grenades) to ensure they met the specifications of their predecessors and the safety requirements for our soldiers to use them safely during training and also in active service.

1.3 REGULATORY DRIVERS

- Resource Conservation and Recovery Act (RCRA), 1976
- Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), 1980

- Clean Water Act (CWA), 1972
- Clean Air Act (CAA), 1970
- Pollution Prevention Act (PPA), 1990
- Executive Order 12856, 1994
- Emergency Planning and Community Right-to-Know Act (EPCRA), 1986

1.4 DEMONSTRATION RESULTS

The objective of this demonstration project was to take the existing technology from the M18 green and yellow smoke grenades and the M83 smoke grenade and combine them for the replacement of the dyes, sulfur, and other components of the M18 red and violet smoke grenades. Substituting a sugar-chlorate formulation smoke and less toxic dyes was successfully implemented for green and yellow M18 smoke grenades and for red, green, and yellow 40 mm projectiles. The red 40 mm smoke grenade was also successfully transitioned to new materials. Similar changes to the red and violet M18 smoke grenades initially proved unsuccessful due to excessive burning of the dyes resulting in the failure of these items to meet military standards for signaling.

Later, with funding provided by the Environmental Security Technology Certification Program (ESTCP), reconfiguration of the red and violet M18 smoke grenades based on the M90 Light Vehicle Obscuration Smoke System (LVOSS) grenade, using redesigned starter patches, proved more effective. The LVOSS grenade was fitted with a new starter patch in order to control excessive burning similar to that experienced with red and violet M18s. The patch slowed the starter mixture's contact with the smoke mix, which allowed the temperature of the mixture to decrease, eliminating extreme flaming. This process was successful for both smokes; however, the transition to the red was not successful due to the coloration of the smoke being less red than required by MILSPECS.

A cost comparison was done for current and new red and violet M18 smoke grenades. It was determined that the production cost increase for a batch of violet M18 smoke grenades in the new configuration can be attributed to the cost of the reformulated, and more expensive, smoke mixture. The opposite is true for a batch of red M18 smoke grenades. Labor costs are lower for both items.

Testing of the M18s was conducted in accordance with Military Standard (MIL-STD) 810F (see Reference 1) at the Pine Bluff Arsenal (PBA) in Arkansas, the DoD's manufacturing facility for smoke grenades.

1.5 STAKEHOLDER/END-USER ISSUES

The program was intended to make the material change completely transparent to soldiers, the end users. The ammunition was tracked by the military Services by utilizing national stock numbers (NSN) and Department of Defense Identification Codes (DoDIC). Labels identifying "Reduced Sulfur Smoke Grenades" were placed on the wire-bound boxes, metal cans, and fiberboard-packing containers. The demonstration plan encompassed two main areas: (1) the First Article test/standard lot testing for the corresponding smoke grenade and (2) a smoke-grenade-based qualification test. Upon completion and attainment of toxicity test requirements,

an Engineering Change Proposal (ECP) was submitted to the Configuration Control Board (CCB) for approval. The CCB makes the final determination as to whether the grenade meets all the standards of the technical data package for procurement. Once approved for production and distribution, the grenade will replace the current M18 red and violet smoke grenade.

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2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY DEVELOPMENT AND APPLICATION

The M18 colored smoke grenade as currently configured consists of a metal can and lid, which holds a mechanically initiated fuze. It is 11.84 cm (4.66 in) high and 6.3 cm (2.48 in) in diameter, excluding the fuze. A pull pin is hinged through the fuze lever, preventing premature initiation. The output of the fuze ignites a starter slug, which in turn ignites the smoke mix fill. After a delay of approximately 15 sec, smoke is emitted from a ½-in core hole for 50 to 90 sec. Figure 1 illustrates the standard configuration of the M18 smoke grenade.

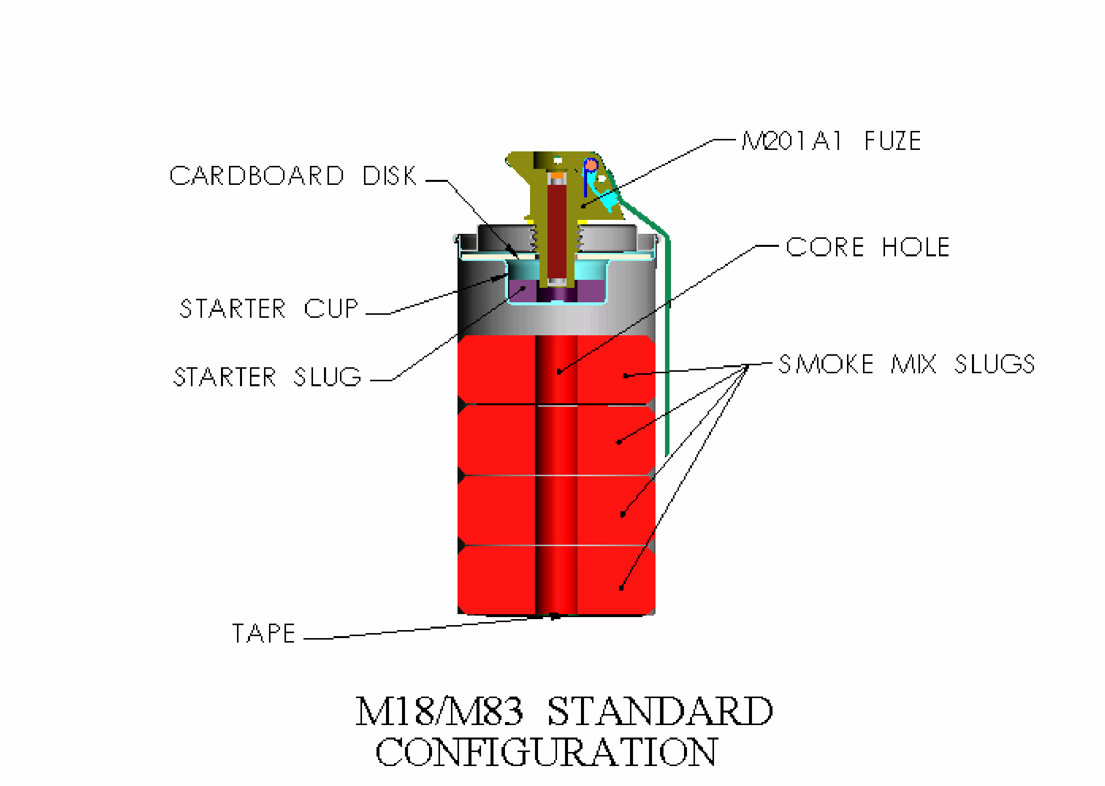

Figure 1. Standard Configuration Diagram for M18 and M83 Grenades.

In the current configuration, the green and yellow smoke mixes use the newer sugar-chlorate formulation, which contains relatively nontoxic dyes. However, the red and violet smoke mixes are still sulfur-chlorate mixes containing toxic dyes. An attempt was made to change the dyes and the sulfur in the red and violet smoke grenades; however, it failed due to the unacceptable flaming of the mixtures during trials. The proposed modifications include the conversion of the red and violet smoke grenades to the sugar-chlorate formulation containing the nontoxic dyes and the use of the new starter patch ignition system. During early development of the LVOSS grenade, tests indicated that the new starter patch system successfully controlled or eliminated excessive flaming by decreasing the temperature of the starter mixture using the patch to slow or stop the starter mixture from coming into excessive, immediate contact with the smoke mixture. Because the test was successful, this new starter patch configuration was tested on the red and violet smoke grenades in an attempt to control excessive flaming (see Figure 2). Both externally and in performance, the modified M18 grenade will be identical to the existing grenade.

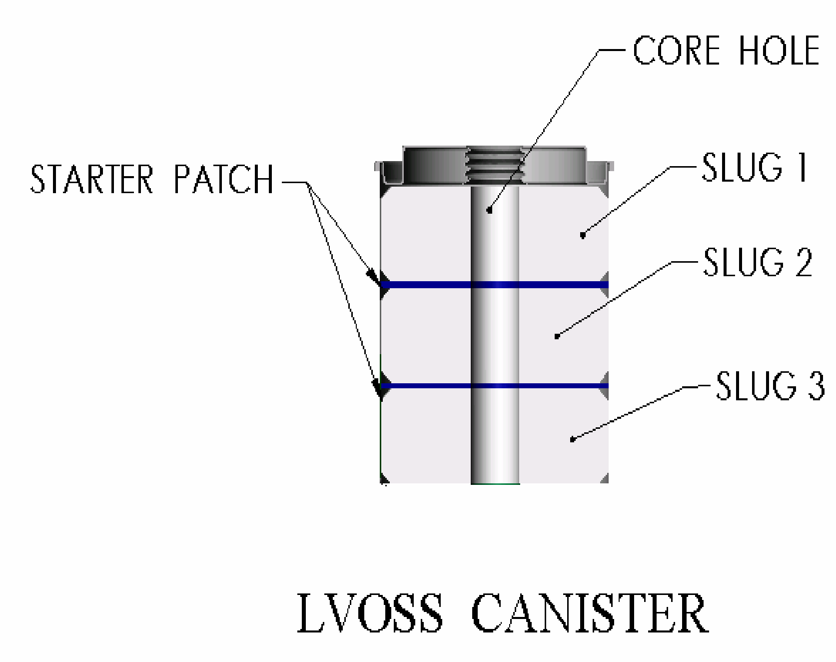

Figure 2. Starter Patch Arrangement.

Although the new dyes used in the red or violet M18 grenades contain different chemical components, the function is no different from that of the old dyes. The dyes still form the visible smoke cloud typically emitted from grenades. The dyes are also still vaporized and dispersed into the atmosphere. Sugar (sucrose) and potassium chlorate react exothermically to form carbon monoxide, water vapor, and potassium chloride. The reaction between sucrose and potassium chlorate is initiated at around 180°C. The most probable reaction mechanism begins with the liquefaction (melting) of sugar and its partial decomposition into fructose and one of several free radicals. The liquid sucrose and decomposition products react with the solid potassium chlorate, thus liberating heat. At around 250°C, magnesium carbonate begins to decompose endothermally into carbon dioxide and magnesium oxide. At approximately 350°C, the remaining potassium chlorate decomposes to potassium chloride and oxygen. Eventually the reaction temperature reaches the sublimation temperature of the dye in the mix and the dye is vaporized and ejected through the grenade core hole. The dye vapor undergoes an adiabatic expansion, mixes with the air and condenses into fine particles that form the visible smoke cloud. Outside temperatures were much lower for the current/original violet grenade and much higher, initially, for the new violet grenade than originally estimated (see Figure 3).

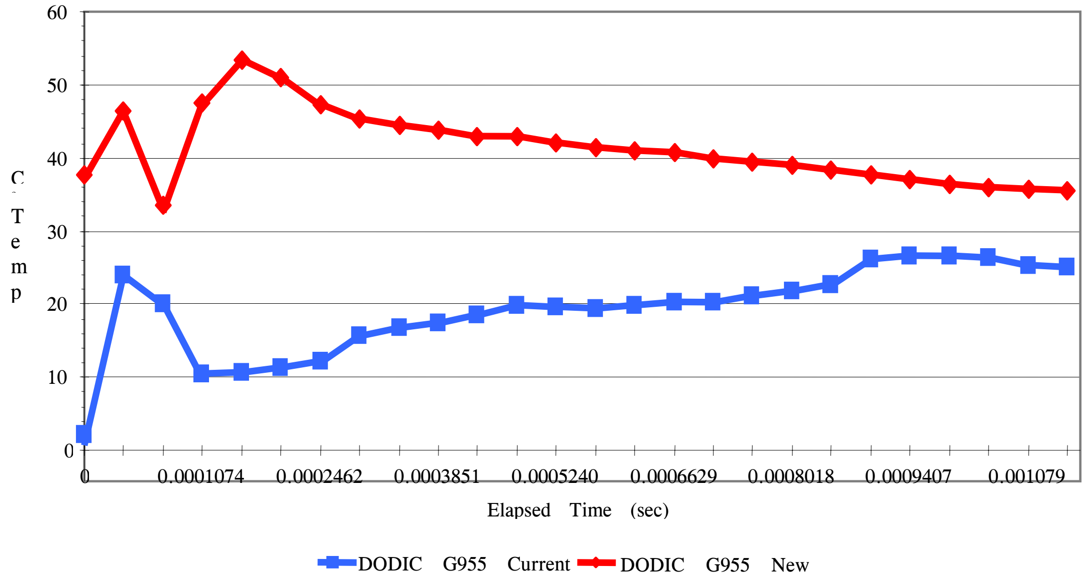

Figure 3. Outside Temperature (ºC x 10) of Violet Smoke Grenades
(current [blue] and new [red])

The key criteria for the new design were (1) meeting MILSPECS, including safety, health, and environmental risk assessment of dyes; (2) thermal characteristics of the dye (decomposition temperature and expected products of decomposition); (3) availability of dyes; and (4) costs.

The selection criteria consisted of those compounds having the appropriate physical and chemical properties of time-released smokes. Of these, the least toxic materials were selected for these studies. A critical selection criterion was the decomposition temperature of the dye. The decomposition temperature must be greater than a sublimation temperature. The greater the difference between the sublimation and decomposition temperatures, the better the candidate. Based on the temperatures shown in Figure 3, it is expected that these temperatures may be much higher than originally expected.

2.2 PROCESS DESCRIPTION

As a result of restrictions placed on the MMR's training activities following the detection of contamination traced to munitions constituents, the ACSIM, as directed by the Chief of Staff of the Army, established a steering committee to address concerns associated with those restrictions. In reference to mobilization, installation, and operational requirements, the ACSIM tasked and provided funding to USAEC to gather data related to the emissions produced by munitions during testing and training activities. As a part of the emissions program, smoke grenades were studied. It was determined that several items contained and emitted toxic and carcinogenic dyes in quantities large enough to present a risk to receptors, including soldiers and production and test personnel.

The switch to noncarcinogenic smoke (a sugar-chlorate formulation) and less toxic dyes was successfully implemented for green and yellow M18 smoke grenades and for red, green, and yellow 40 mm projectiles. Similar changes to the red and violet M18 smoke grenades initially proved unsuccessful due to excessive burning of the dyes, resulting in the failure of the items to meet military standards for obscurants. Later, with funding provided by ESTCP, reconfiguration of the red and violet M18 smoke grenades, based on the M90 LVOSS grenade and utilizing redesigned starter patches, proved more effective. Depictions of the current and new technology designs can be noted in Figures 1 and 2.

The LVOSS grenade was fitted with a new starter patch in order to control burning similar to that experienced with red and violet M18s. The patch slowed the starter mixture's contact with the smoke mix allowing the temperature of the mixture to decrease, which eliminated excessive flaming (see Figure 3). The modified M18s, with sugar-chlorate formulation dyes and starter patches, are visually and functionally identical to existing M18s, so no new training requirements are needed in order to use these items. The reconfiguration of the grenade to utilize a new starter patch was the single most significant modification that PBA made to the assembly process.

The M18s and M83s tests were conducted in accordance with MIL-STD 810F (see Reference 1) at PBA. The U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM) is presently assessing health and safety requirements for the current grenade configuration, including toxicity studies for the current and new violet smoke grenades.

2.3 PREVIOUS TESTING OF THE TECHNOLOGY

The original colored smoke grenades were tested in the 1980s and were determined to be toxic (see Reference 2). Supplemental data gathered in the 1990s is noted in References 3 through 8. Due to the determination of toxicity, an attempt was made to change all four colored dyes. During testing of the developmental violet dye, it was determined that the new smoke was more toxic than the original and use of the dye (Blue Disperse 3) was abandoned (see Reference 5). The components for the original yellow and green smoke grenades were changed, successfully tested, and transitioned into production. Based on that success, the yellow, green, and red 40 mm projectiles and the green and yellow M18 smoke grenades were type classified based on their successful transition from toxic dyes to less toxic dyes and sulfur to sugar chlorate mixes. The testing of the red and violet dyes was not successful (due to excessive flaming during burning) so the formulation was left unaltered to maintain functionality.

The starter patches were successfully tested in the LVOSS M90 grenades. The M90 grenade was type classified in August 1997 and production of this grenade began in FY98. Based on the use of the starter patches for the M90 grenade in FY98, it was believed that this technology would stop the excessive flaming of the red and violet smoke grenades such that the new formulation could be used. This was demonstrated in the test entitled "M18 and M83 Grenade Reliability and Performance Improvements — Report on Engineering Design Testing M18 and M83 Grenades with Starter Patch Configuration" (see Reference 9). Replacement of the HC with the terephthalic acid/pentaerythritol (TA/PE) mix is not part of this demonstration plan, but the success of the starter patches in this demonstration will encourage additional testing of the starter patches for this additional application.

2.4 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

2.4.1 Advantages

One advantage of the technology is that it allows soldiers to use more environmentally friendly items during training and times of conflict. It also decreases risk to soldiers during testing and training exercises by removing potentially toxic materials. Having access to new, less toxic materials will allow for more extensive use of them during training. As a result, soldiers will be able to participate in more realistic training exercises that will ultimately increase their combat readiness. In the past, burn times of the mixes caused some limitations. However, demonstrations have shown that the new starter patch technology provides equivalent performance (for violet smoke) to the current technology with regard to color and burn time. The new technology allows a more uniform (cooler) temperature to be achieved during the initial burning of the grenades, which eliminates the excessive flaming of the smokes.

2.4.2 Disadvantages

One disadvantage of the technology is that while material replacements eliminate the sulfur emissions relatively inexpensively, the replacement of dyes is a significantly greater cost. Therefore, it is essential that dye costs be aggressively controlled. Another limitation is that the red smoke simply did not meet performance objectives.

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3.0 DEMONSTRATION DESIGN

3.1 PERFORMANCE OBJECTIVES

The colored smoke grenades have met the performance objectives listed in paragraphs 3.4, 3.5, 3.6, and 3.8 of MIL-G-12326K Environmental Assessment (EA) with Amendment 3 (April 21, 1989). Destructive testing was completed in accordance with paragraph 4.4.2.2 of MIL-G-12326K and MIL-STD-105 Level S-4, and smoke emission time is equivalent to that segment of the sample specified in MIL-STD-414, Level II. Performance objective criteria and level of attainment are outlined in Table 1.

Table 1. Performance Objectives.

Type of Performance Objective	Primary Performance Criteria	Expected Performance (Metric)	Actual Performance Objective Met?
Quantitative	Better than or equal performance to MILSPECS (paragraphs 3.4, 3.5, 3.6 and 3.8 of MIL-G-12326K w/ Amendment 3)	Pass individual product tests as prescribed in the MIL-STD	Met
Qualitative	Smoke will be equal in quantity and quality.	Smoke will meet requirements of MIL-STD	Met (violet) Coloration of red too light.

3.2 SELECTION OF TEST PLATFORM/FACILITY

The M18 Red and Violet Smoke grenades were chosen because they had not been previously addressed. The M18 smoke grenades of other colors (green and yellow) had been changed under prior work efforts.

The test facility chosen for these studies was PBA, which is the facility used by DoD for smoke grenade manufacturing. For this reason, PBA was the ideal facility to ensure successful transition from the grenade testing stage to the manufacturing stage. Since PBA is the manufacturer, the technology transfer will be seamless and immediate upon approval of the new grenade formulations. In addition, the infrastructure for testing new formulations already exists at PBA.

Dugway Proving Ground (DPG) is the designated test facility for emissions characterization of the smoke and pyrotechnic items for USAEC’s emission characterization program. Because DPG has previously tested the M18 smoke grenades (red and violet), it was the ideal facility to test the new grenades as they were produced. Test results from the old M18 smoke grenades (red and violet), could be compared to the test results from the new grenades to ensure that a more environmentally friendly alternative had been manufactured.

3.3 TEST FACILITY HISTORY/CHARACTERISTICS

3.3.1 Pine Bluff Arsenal

The grenades were manufactured on site at PBA. PBA was established in 1941 to load incendiary bombs and expanded during WWII to manufacture, load, and store war gases and to fill smoke and white phosphorus munitions. This mission continues today.

PBA, located in southeast Arkansas, is 35 miles southeast of Little Rock and 8 miles northwest of the City of Pine Bluff. PBA is bordered on the east by the McClellan Kerr Arkansas River Navigation System and on the west by the Union Pacific Railroad and U.S. Highway 65, making it directly accessible by rail, road, or waterway. PBA is 8½ miles long by 24¾ miles wide and covers 14,944 acres. It includes 952 buildings, which provide 3.3 million square ft^2 of floor space, including storage bunkers. It also has 42 miles of railroad track and 2 million yd^2 of roads and paved surfaces.

The objective of the engineering design test (EDT) is to determine the performance characteristics of new items or proposed modifications. For this reason, the test items input into EDT are frequently manufactured in whole or in part at the Production Engineering Laboratory (PEL) located at PBA or on specially set up pilot lines with specially trained operators. Items manufactured for the EDT are rarely marked in accordance with the technical data package (TDP). Product quality test (PQT) items, on the other hand, are usually manufactured wholly on arsenal production lines with the same operators and procedures used during normal operations.

3.3.2 Dugway Proving Ground and the Smoke Characterization Test Chamber

DPG, covering 798,855 acres, is located in the Great Salt Lake Desert, approximately 85 miles southwest of Salt Lake City, Utah. Surrounded on three sides by mountain ranges, the proving ground's terrain varies from level salt flats to scattered sand dunes and rugged mountains. The DoD has designated DPG as a major range and testing facility, and the primary chemical and biological defense-testing center under the Reliance Program. Testers here determine the reliability and survivability of all types of military equipment in a chemical or biological environment.

The BangBox facility at DPG is a 1,000-m^3 dome that contains a steel blast-shield and analytical equipment. Under the air-supported roof, made from the same polyvinyl material as many swimming pool covers, researchers can test up to a half-pound of explosives per blast or five pounds of propellant per burn. Its sophisticated sampling equipment provides on-the-spot readings of open burn/open detonation (OB/OD) emissions to the parts-per-trillion level.

The smoke characterization test chamber, hereinafter referred to as the smoke chamber, is located near the BangBox facility and adjacent to the instrument building. It is much smaller than the BangBox and is used for testing small items. It is lined with aluminum and is fairly easy to clean. The smoke chamber (see Figures 4 and 5) was designed and constructed as a result of collaboration among the BangBox Test Team, the U.S. Environmental Protection Agency (EPA), Oregon Graduate Institute (OGI), and URS Corporation.

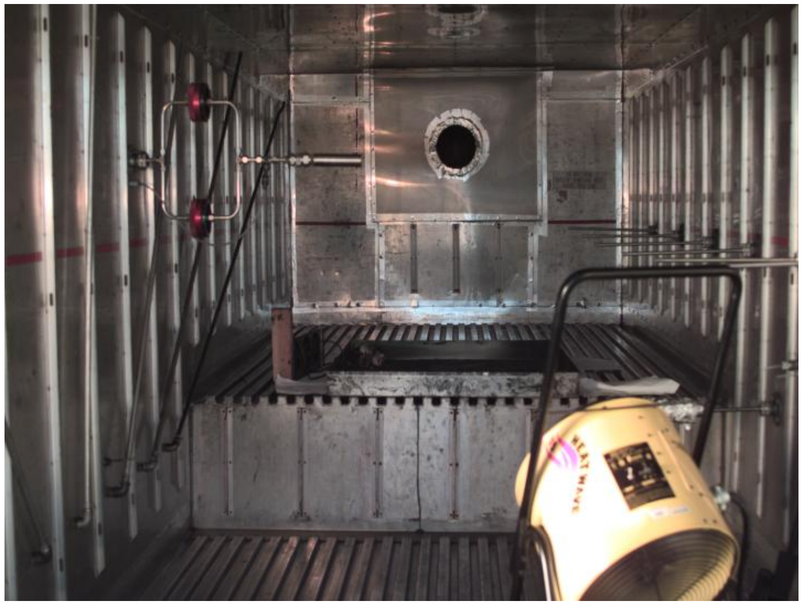

Figure 4. Inside the Smoke Characterization Test Chamber.

Figure 5. Outside the Smoke Characterization Chamber.

The smoke chamber is approximately 7 ft wide, 20 ft long, and 6 ft tall for two-thirds of its length and 5 ft tall for the remainder. The interior volume of the smoke chamber is approximately 820 ft^3. The chamber is sealed before deploying the test item. Fans inside the chamber keep the gases mixed during sampling. Gas samples are extracted from the gas chamber through short stainless steel probes. Eleven sampling ports have been installed on the smoke chamber for manual method sampling—two ports for sampling volatile organic compounds (VOC) and tracer gas, two ports for sampling semi-volatile organic compounds (SVOC), two ports for dioxins/furans, two ports for sampling total suspended particulates TSP,

one port for particle sizing and two ports for sampling HCl. A dual-line filtered and heated sampling manifold has been installed for continuous monitoring of CO, CO_2, NO_x, SO_2, and HCl. The sample media is located immediately outside the chamber. Six ½-in vent lines distributed evenly along one side allow ambient air to enter the chamber to replace the gases removed by the sampling trains.

After sampling has concluded, dampers are opened and the chamber is pressurized and vented through a stainless steel stack. An electrical firing circuit has been installed that remotely deploys the test items and releases the SF6 tracer gas.

For additional information on how the test chambers at DPG were used to capture emissions data from smoke grenades, please refer to Appendix G in the Final Technical Report (see Reference 13).

3.4 PHYSICAL SETUP AND OPERATION

The basis of the testing and evaluation is shown in Figure 6. This testing strategy is the current test methodology used by PBA to test and produce a new formula for M18 red smoke grenades. The method of testing M18 violet smoke grenades is similar to that of M18 red smoke grenades. As was discussed in Section 2.2, the single most significant modification that PBA made to the assembly process was fitting the grenade with a new starter patch instead of the starter slug.

The average burn time for M18 grenades must fall within the range specified in the military standard (50 to 90 sec at ambient conditions). Standard hypothesis testing techniques were used to determine whether an improvement was actually realized.

3.4.1 Demonstration Setup and Start-Up

The demonstration was performed at PBA, which regularly produces smoke grenades and performs acceptance testing for smoke grenades. The testing performed under this demonstration was done in accordance with the PBA standard operating procedures (SOP) shown in Appendix A from the Final Technical Report (see Reference 13). The protocols identified in the PBA SOPs include all aspects for test and demonstration operations to be conducted under this demonstration effort. The SOPs also contain guidelines covering all aspects and concerns regarding health and safety and identify all appropriate requirements for regular scheduled briefings, hazard assessments and risk analyses, emergency procedures, operational procedures, reporting requirements, and other worker related safety information. The sulfur chlorate mixtures in the red and violet smoke grenades were replaced with a sugar-chlorate mixture and the starter mixtures were replaced with a starter mixture and patches similar to those used in the M90 LVOSS grenade and the testing done on the M83 and M18 smoke grenades.

PBA regularly performs tests for lot acceptance. PBA tests for weight, material, dimensions, function, and color of the smoke for grenades on a lot-to-lot basis. The grenades must meet these requirements as outlined by the Technical Data Package Drawing #13-19-37 (M18 Red and Violet Smoke Grenade) and the MIL-STD, MIL-G-12326K (EA).

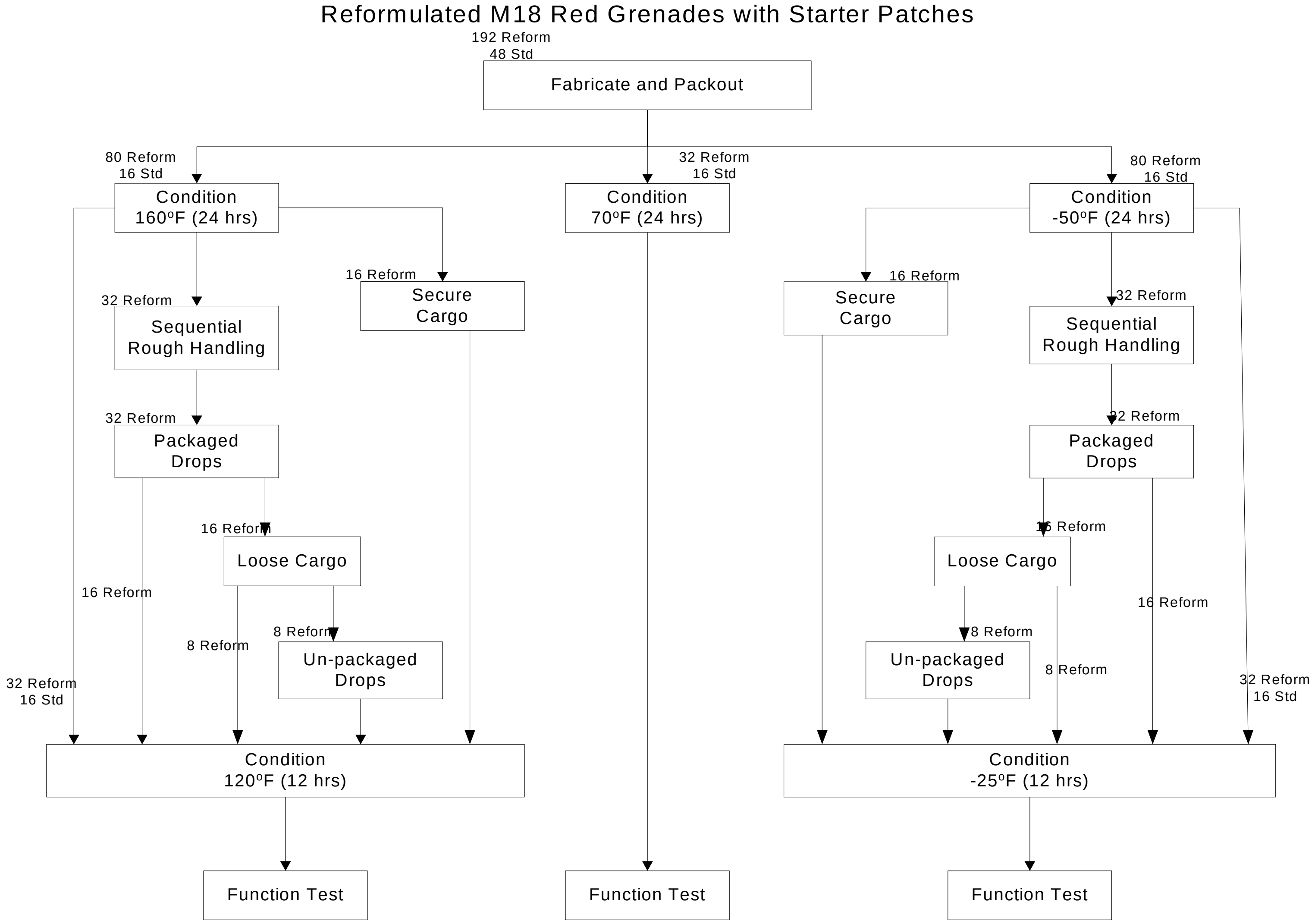

Figure 6. Method of Testing M18 Red Smoke Grenades.

3.4.2 Period of Operation

Table 2 is based on the actual schedule of demonstration as it occurred during this project. Due to delays in purchasing the dyes, a January 2003 accident at PBA, and delays in obtaining funding, the original schedule was modified to reflect what actually occurred.

Table 2. Schedule for Demonstration of Colored Smokes (red and violet).

PHASE	2003			2004	2005		
	FEB	MAR	JUL		FEB	MAR-JUL	AUG-SEP
Grenades ready (except violet)	♦						
Testing							
Results	♦						
Buy dye							
Violet test grenade							
Testing			♦				
Results							
Work with in process team (IPT)							
Toxicity testing							
Complete ECP							♦
Complete final report							♦
Complete Cost and Performance (C&P) Report							♦

3.4.3 Operating Parameters for the Technology

The new configurations use a "starter patch" rather than a "starter slug." This means that there will be no need for 30-lb batches of starter mix. A single production lot of starter patches is approximately 12,000 (a sufficient quantity to make 6,000 grenades). A production batch of colored Smoke Mix is 800 lb and usually produces more than 208 grenades. However, most of the test work was done using 30-lb batches of Smoke Mix made in PBA's Pilot Facility. These 30-lb batches produced the test grenades (approximately 30-40) that were used to determine if the smoke and the smoke grenades met the requirements in the MIL-STD. Production-sized batches were not prepared until the test grenades met the requirements and the mixture and configuration were ready for confirmation testing in the production line. Starter patches were from a production lot of starter patches.

3.4.4 Experimental Design

The preliminary testing consisted of mixing a 30-lb batch of the new materials and using all the material to fill as many grenades as possible (typically 30-40 grenades). These grenades were tested in accordance with PBA EDT procedures to ensure the batches met the operational and test criteria as outlined in the EDT protocols and as shown in Section 3.1, Performance

Objectives, and in Table 1. The materials used in the old versus the new smoke grenades are shown in Table 3, Red Smoke Mix, and Table 4, Violet Smoke Mix.

Table 3. Red Smoke Mix (Both old and new)**.**

Component	**Old Weight Fraction[1] (w/w)[*]**	**New Weight Fraction[1] (w/w)[*]**	**CAS #**
Disperse Red 9	0.4000	0.0000	82-38-2
Solvent Red 1	0.0000	0.3160	1229-55-6
Disperse Red 11	0.0000	0.1390	2872-48-2
TA	0.0000	0.0660	100-21-0
Sulfur	0.0900	0.0000	7704-34-9
Sugar	0.0000	0.1420	57-50-1
Magnesium carbonate	0.0000	0.0870	546-93-0
Potassium chlorate	0.2600	0.2160	3811-04-9
Stearic acid	0.0063	0.0050	57-11-4
Sodium bicarbonate	0.2500	0.0340	144-55-8
Polyvinyl alcohol	0.0200	0.0200	9002-89-5
Components/Materials Added			
Starter patch			
Sugar			57-50-1
Solvent Red 1			1229-55-6
Disperse Red 11			2872-48-2
TA			100-21-0
Magnesium carbonate			546-93-0
Components/Materials Eliminated			
Disperse Red 9			82-38-2
Starter slug			
Starter cup			
Cardboard disc			
Sulfur			7704-34-9

Notes:
(1) The sum of the weight fractions need not equal 1; they reflect a granular fraction formula.
(*) weight to weight

Table 4. Violet Smoke Mix (old and new)**.**

Component	Old Weight[1] Fraction (w/w)[*]	New Weight[1] Fraction (w/w)[*]	CAS #
Violet dye mix[2]	0.4000	0.0000	
Disperse Red 11	0.0000	0.3803	2872-48-2
TA	0.0000	0.0766	100-21-0
Sulfur	0.0900	0.0000	7704-34-9
Sugar	0.0000	0.1550	57-50-1
Magnesium carbonate	0.0000	0.1020	546-93-0
Potassium chlorate	0.2600	0.2350	3811-04-9
Stearic acid	0.0063	0.0050	57-11-4
Sodium bicarbonate	0.2500	0.0510	144-55-8
Polyvinyl alcohol	0.0200	0.0200	9002-89-5
Components/Materials Added			
Starter patch			
Sugar			57-50-1
Disperse Red 11			2872-48-2
TA			100-21-0
Magnesium carbonate			546-93-0
Components/Materials Eliminated			
Disperse Red 9[2]			82-38-2
1,4-diamino-2,3-dihydroanthraquinone (DDA)[2]			81-63-0
Starter slug			
Starter cup			
Cardboard disc			
Sulfur			7704-34-9

Notes:
(1) The sum of the weight fractions need not equal 1; they reflect a granular formula.
(2) Violet dye mix is a mixture of approximately 80% DDA and 20% Disperse Red 9.
(*) weight to weight

The starter patches, which replaced the starter slugs, are at the heart of the success of these two grenades. The success of this program is due to PBA's hard work and persistence. The materials used to make the starter patches are shown in Table 5.

Table 5. Starter Patch Components.

Starter Patch		
Component	**New Weight Fraction[1] (w/w)[*]**	**CAS #**
Terry cloth patch (1.5 in x 1.5 in)	NA	
Impregnating Slurry		
Charcoal	0.3525	7440-44-0
Sodium nitrate	0.1475	7631-99-4
Gum arabic	0.0004	9000-01-5
Water	0.4600	7732-18-5

Notes:
(1) The weight fractions need not equal 1 because they reflect a granular formula.
(*) weight to weight

The starter patch components, shown above, will increase the burn time for the TA, as was demonstrated for the colored smokes. Earlier work at PBA indicated that the addition of small amounts of sodium bicarbonate (approximately 0.0083%) to the mix along with the magnesium carbonate (approximately 0.0383%) decreased the temperature sensitivity of the mix. In the first phase, PBA manufactured grenades using this new starter patch configuration and fill. These grenades were submitted to the production validation test (PVT) to validate the design. Approximately 30-40 grenades were produced and tested as part of the testing requirements. These grenades were tested in accordance with MIL-G-12326K (EA). Once this design is validated (not as part of this plan), the fills of all HC-filled munitions can be replaced with this new fill. This follow-on effort is not included as a part of this demonstration.

3.5 SAMPLING AND MONITORING PROCEDURES

3.5.1 Product Testing

Once the material met the EDT criteria, a production batch of smoke mix was prepared (800 lb of smoke material) from which approximately 208 grenades were manufactured. Twenty percent of the grenades manufactured were then tested in accordance with MIL-G-12326K and other appropriate MIL-STDs, which can be found in Appendix A from the Final Technical Report (see References 1 and 13).

This demonstration did not include plans to test or produce the M4A3 (HC-filled smoke pots). The M8 has already been type classified and fielded for training use. PBA does plan to replace the HC mixture with the sugar chlorate mixture based on the success of the starter patches. This follow-on effort is not included as a part of this demonstration.

The grenades were also sent to DPG and to USACHPPM to ensure that they meet the smoke requirements for performance.

The primary thrust of this effort was to successfully complete a PVT for the M18 red and violet colored smoke grenade. The transition to less toxic dyes and compounds was successful for the green and yellow M18 grenades as well as the red, green, and yellow 40-mm projectiles. The transition in the 1980s to a less toxic M18 red grenade was unsuccessful due to excessive

flaming, which interrupted the production of the colored smoke. While a final full-production run of more than 208 grenades was completed, not all criteria were successfully met. The grenades did not flame, burned the appropriate amount of time, and met the hot and cold testing and transportation requirements; however the smoke produced by the grenades was too light. Instead of producing the necessary red smoke, a pink smoke was generated. The violet-colored smoke grenade met all the above criteria, including the criteria for smoke color. Based on this success, the emissions were tested (including the old red and violet smokes), and results are shown in Appendix G from the Final Technical Report (see Reference 13).

One of the technology transfers from the above work is that PBA will be able to increase the burn time of the M83 TA grenade by changing the configuration and formulation of that grenade. With improved burn time, the grenade will replace the M8 HC smoke grenade.

For additional information on the sampling procedures, refer to Appendix C from the Final Technical Report (see Reference 13).

3.6 ANALYTICAL PROCEDURES

3.6.1 Selection of Analytical and Testing Methods

USAEC established analytical and testing methods to ensure that the emissions generated from the new smokes will be more environmentally friendly than the old formulations. This test plan has been coordinated extensively within the EPA. For additional information, refer to Appendix G from the Final Technical Report (see Reference 13).

Actual testing of the grenades was completed in accordance with MILSPECS MIL-G-12326K(EA), MIL-G-12326K, and MIL-G-12326K Amendment #3; and MIL-STD 810F (see Reference 1).

3.6.2 Selection of Analytical and Testing Laboratory

The analytical laboratories at DPG were selected for environmental testing of the new smoke formulations. For additional information, please refer to Appendix G from the Final Technical Report (see Reference 13).

3.6.3 Additional Testing on Rats at USACHPPM

Additional environmental testing of the new smoke formulations is being performed on rats at USACHPPM. USAEC will provide results to ESTCP on completion of testing.

4.0 PERFORMANCE ASSESSMENT

4.1 PERFORMANCE DATA

USAEC received performance data only in an analyzed format. No raw data was provided. Tables 7 and 8 indicate which criteria passed and which criteria failed.

4.2 PERFORMANCE CRITERIA

Table 6 describes the general Performance Objectives used to evaluate the performance of the M18 colored smoke grenades.

Table 6. Performance Criteria.

Performance Criteria	Description	Primary or Secondary
Product testing		Primary
Extreme temperature function	The lot of grenades randomly separated into three groups—hot, ambient, and cold; each group maintained for 24 hr at 160ºF, 70ºF and -50ºF.	Primary
Sequential rough handling	Subjected to rough handling by a machine for 24 hr.	Primary
Secure cargo	Subjected to secure cargo handling by a machine for 24 hr.	Primary
Packaged drops	Subjected to drops while in packaging	Primary
Loose cargo	Subjected to mechanical motions simulating movements as loose cargo	Primary
Un-packaged drops	Subjected to dropping while unpackaged	Primary
Extreme temperature function	Subjected to temperature conditioning of 120ºF and -25ºF for 12 hr.	Primary
Function test	Grenades functioned to determine quality of smoke, burn time, % of flaming, and color of smoke	Primary

The above performance criteria were used to evaluate the two candidates for replacement of the M18 red and violet colored smoke grenades. During the demonstration of these two candidates, the starter patch configuration that PBA invented worked perfectly. The M18 violet smoke grenade functioned as designed and met the performance criteria (see Figure 7). The color of the M18 red smoke grenade was lighter than intended so two more pilot tests were performed to ensure that the red was darker (see Figure 8). It was determined that the addition of TA (which alone creates a white smoke) was the cause of the pale coloration of the new red smoke formulation. The M18 red smoke grenade was dropped from the test plan after several attempts to alter the color of the smoke were unsuccessful. The color of the smoke was a light red (pink) (see Figure 8). As a result, the Program Managers-Close Combat System (PM-CCS) did not feel the new color met the MIL-STD requirements for the smoke. The burn time, replacement of the sulfur with sugar, replacement of the dyes, and lack of flaming were all successful.

Figure 7. Violet Smoke Grenade.

Figure 8. Side-by-Side Comparison of New M18 Red Smoke Mix with Standard M18 Red Grenade.
Note: Standard M18 Grenade is on the right.

As a result of this program, the PM-CCS created the Smoke and Dye IPT to take a much broader approach in addressing issues associated with the colored smokes. This broader approach will include research aimed at additional dyes, fuels, fuzing, plating materials, and other less toxic materials for the colored smoke grenades.

The colored smokes performance confirmation methods and actual performance are shown in Tables 7 and 8.

Table 7. Actual Performance and Performance Confirmation Methods for M18 Red Smoke.

Performance Criteria	Expected Performance Metric (Pre demo)	Performance Confirmation Method	Actual Performance (Post demo)
Product testing	Must pass individual product tests specified in the MIL-G 12326K (EA) and MIL-STD 810F summarized below (see Reference 1)	MIL-G 12326K (EA) MIL-STD 810F	While it successfully passed all of the criteria in the specification, the coloration was determined to be too light.
Extreme temperature function	The lot of grenades are randomly separated into three groups—hot, ambient, and cold. Each group is maintained for 24 hr at 160ºF, 70ºF, and -50ºF. The two extreme temperatures (hot and cold) had 96 grenades in each group, and the ambient group had 48 grenades.	Functioned as designed	Passed (The coloration was determined to be too light.)
Rough handling	33% of the two extreme temperature groups were subjected to rough handling by a machine for 24 hr.	Functioned as designed	Passed (The coloration was determined to be too light.)
Secure cargo	16% of the two extreme temperature groups were subjected to secure cargo handling by a machine for 24 hr.	Functioned as designed	Passed (The coloration was determined to be too light.)
Packaged drops	33% of the two extreme temperature groups were subjected to rough handling and then to packaged drops. Half of these are temperature conditioned and then function tested.	Functioned as designed	Passed (The coloration was determined to be too light.)
Loose cargo	Half of the packaged dropped grenades are then handled as loose cargo. The other half are temperature conditioned for 12 hr and function tested.	Functioned as designed	Passed (The coloration was determined to be too light.)
Unpackaged drops	The remaining half of the loose cargo test are removed from their package and dropped. These are then temperature conditioned and function tested.	Functioned as designed	Passed (The coloration was determined to be too light.)
Ambient temperature function	The ambient temperature grenades (48) functioned as designed.	Functioned as designed	Passed (The coloration was determined to be too light.)
Extreme temperature function (2d)	50% of the two extreme temperature groups were subjected to 12 more hr of a change in temperature extreme to 120ºF and -25ºF respectively.	Function tested	Passed (The coloration was determined to be too light.)

During initial pilot production of the violet grenade, all test criteria were met.

Table 8. Actual Performance and Performance Confirmation Methods for M18 Violet Smoke.

Performance Criteria	Expected Performance Metric (pre-demo)	Performance Confirmation Method	Actual Performance (post-demo)
Product testing	Must pass individual product tests specified in the MIL-G 12326K (EA) and MIL-STD 810F summarized below (see Reference 1)	MIL-G 12326K (EA) MIL-STD 810F	**Passed**
Extreme temperature function	The lot of grenades are randomly separated into three groups—hot, ambient, and cold. Each group is maintained for 24 hr at 160ºF, 70ºF, and -50ºF. The two extreme temperatures (hot and cold) had 96 grenades in each group, and the ambient group had 48 grenades.	Function tested	**Passed**
Rough handling	33% of the two extreme temperature groups were subjected to rough handling by a machine for 24 hr.	Function tested	**Passed**
Secure cargo	16% of the two extreme temperature groups were subjected to secure cargo handling by a machine for 24 hr.	Function tested	**Passed**
Packaged drops	33% of the two extreme temperature groups were subjected to rough handling and then to packaged drops. Half of these are temperature conditioned and then function tested.	Function tested	**Passed**
Loose cargo	Half of the packaged dropped grenades are then handled as loose cargo. The other half are temperature conditioned for 12 hr and function tested.	Function tested	**Passed**
Unpackaged drops	The remaining half of the loose cargo test are removed from their package and dropped. These are then temperature conditioned and function tested.	Function tested	**Passed**
Ambient temperature function	The ambient temperature grenades (48) functioned as designed.	Function tested	**Passed**
Extreme temperature function (2d)	50% of the two extreme temperature groups were subjected to 12 more hr of a change in temperature extreme to 120ºF and -25ºF respectively.	Function tested	**Passed**

4.3 DATA EVALUATION

During the initial purchase of dyes, product searches on the Internet indicated that the most cost-effective dyes are produced in foreign countries such as India and China. However, these dyes can be somewhat difficult to obtain directly from foreign sources because current laws require sources to purchase American products. To complicate the issue further, the dyes do not normally meet specifications for material content, particle size, and particle shape, which often

means that entire lots of grenades may not function as designed and must be rejected. The chief concern is that testing requires a consistency of the purchased material. Material specifications are currently being modified to reflect this concern.

As part of this program, it was determined that the dyes could be tested for purity using differential scanning calorimetry (DSC). The dyes were tested using this process with Solvent Red #1 having a purity of 98.2-98.5% and Disperse Red #11 having a purity of 98.6-98.9%. Appendix H in the Final Technical Report highlights these results (see Reference 13). The results also mention that because of good thermal stability in the melt stage, Solvent Red #1 may be purified further by using zone-melt techniques, but because of the volatility of Disperse Red #11 in the melt phase, it is not a good candidate for zone refining.

The overall internal profile of the grenade was reduced during manufacturing because of the use of the starter patches. This eliminated a common manufacturing problem in which the top slug was sometimes knocked out of the grenade. Grenades that were packaged with one less slug were rejected on a regular basis. In addition, the use of starter patches has reduced the number of labor hours required to produce the new colored smoke grenades. By reducing the labor hours, a cost savings of approximately 17.2% has been achieved for an 800-lb batch of new colored smoke grenades (see Tables 10 and 11).

4.4 TECHNOLOGY COMPARISON

4.4.1 Violet M18 Smoke Grenade

All testing criteria were successfully met during initial pilot production of the reconfigured violet grenade. The burn time, replacement of the sulfur with sugar, replacement of the dyes, and lack of flaming were all successful resulting in PM-CCS determining that the reconfigured violet M18 meets current MIL-STDs for use. Additionally, there is no discernable difference in the outward appearance, making the transition to the reconfigured grenades transparent to the end users.

4.4.2 Red M18 Smoke Grenade

While testing criteria were successfully met during the initial pilot production of the reconfigured red grenade, the smoke produced was a much lighter red (pink) than intended. It was determined that the addition of TA (which alone creates a white smoke) was the cause of the light coloration of the new red smoke formulation, and PM-CCS determined that the new color failed to meet the MIL-STD requirements for the produced smoke. The M18 red smoke grenade was dropped from the test plan after several attempts to alter the color of the smoke were unsuccessful.

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5.0 COST ASSESSMENT

5.1 COST REPORTING

Table 9 shows the cost comparison of the materials used for reduced sulfur smoke grenades versus the sulfur fueled smoke grenades. This is shown as a per grenade cost. For a per batch cost, refer to Tables 10 and 11. There is a cost savings with regard to capital equipment costs and other initial investment costs because the same equipment and process are used to formulate the "new" grenades as was used to formulate the "current" grenades. Training is not included in the labor cost because training is not required. Indirect environmental costs of the current and new technologies were not addressed because that information was not provided by PBA. For additional calculations, please refer to the Appendices from the Final Technical Report (see Reference 13).

Table 9. Cost Comparison of Reduced Sulfur Red and Violet Smoke Grenades.

Component	Current Red Formulation	New Red Formulation	Current Violet Formulation	New Violet Formulation
Smoke mix	\$6.44	\$4.87	\$2.77	\$3.57
Grenade body	\$0.74	\$0.74	\$0.74	\$0.74
Grenade lid	\$0.45	\$0.45	\$0.45	\$0.45
M201A1 fuze	\$5.32	\$5.32	\$5.32	\$5.32
Starter cups	\$0.071	-	\$0.71	-
Cardboard disc	\$0.009	-	\$0.009	-
Starter slug	\$0.114	-	\$0.114	-
Starter patch	-	\$0.472	-	\$0.472
Labor	\$4.95	\$3.93	\$4.95	\$3.93
TOTAL (PER GRENADE)	\$18.09	\$15.78	\$15.06	\$14.48

Notes:
(1) Table 9 labor values are per grenade.
(2) Data was provided by PBA.

5.2 COST ANALYSIS

The per grenade costs listed in Table 9 were compared to determine the actual costs of manufacturing (see Tables 10 and 11). Red costs have been added because they are known based on the demonstration plan. These costs would normally be added to the cleanup costs associated with original smoke grenades, and then would be compared to the new less-toxic smoke grenades to determine the environmental cleanup costs that might result. Unfortunately, the cleanup costs for the original grenades have never been determined because no effort has been made to clean up after them. It is therefore not known what the difference in cost might be. There are ongoing efforts to determine if there is any environmental impact from perchlorates (smoke grenades do not contain perchlorates) that are emitted from the smoke grenades (and other munitions) during the burning process or as residues. However, these studies are still ongoing. Therefore, the cost analysis will be from the point-of-view of manufacturing, reduction of the heavy metals from the dyes, use of a safer dye, and the elimination or reduction of the sulfur from the smoke grenades. Due to the new grenade configuration and thus a potential

reduction in rejects on the manufacturing line, it is expected that a different number of grenades per batch will be produced.

Table 10. Violet Smoke Mix (current and new)**.**

Component	Current Weight Fraction[1] (w/w)[*]	New Weight Fraction[1] (w/w)[*]	CAS #	Cost Per Batch	
				Current	New
Violet dye mix[2]	0.4000	0.0000	81-63-0 82-38-2	$2,553.40	$0
Disperse Red 11	0.0000	0.3803	2872-48-2	$0	$3,107.60
TA	0.0000	0.0766	100-21-0	$0	$84.57
Sulfur	0.0900	0.0000	7704-34-9	$17.28	$0
Sugar	0.0000	0.1550	57-50-1	$0	$93.00
Magnesium carbonate	0.0000	0.1020	546-93-0	$0	$61.20
Potassium chlorate	0.2600	0.2350	3811-04-9	$147.68	$133.48
Stearic acid	0.0063	0.0050	57-11-4	$11.10	$8.88
Sodium bicarbonate	0.2500	0.0510	144-55-8	$44.00	$8.98
Polyvinyl alcohol	0.0000	0.0200	9002-89-5	$0	$75.56
TOTAL				$2,773.46	$3,573.27
Components/Materials Added					
Starter patch					
Sugar			57-50-1		
Disperse Red 11			2872-48-2		
TA			100-21-0		
Magnesium carbonate			546-93-0		
Components/Materials Eliminated					
Disperse Red 9			82-38-2		
DDA			81-63-0		
Starter slug					
Starter cup					
Cardboard disc					
Sulfur			7704-34-9		

Notes:
(1) The weight fractions need not equal 1 because they reflect a granulated formula.
(2) Violet dye mix is a mixture of approximately 80% DDA (CAS #81-63-0) and 20% Disperse Red 9 (CAS #82-38-2).
(3) The labor cost to produce one batch of current violet smoke grenades is $4,375.14.
(4) The labor cost to produce one batch of new violet smoke grenades is $3,624.19.
(*) weight to weight

Table 11. Red Smoke Mix (current and new).

Component	Current Weight Fraction[1] (w/w)*	New Weight Fraction[1] (w/w)*	CAS #	Cost Per Batch	
				Current	New
Disperse Red 9	0.4000	0.0000	82-38-2	$6,224	$0
Solvent Red 1	0.0000	0.3160	1229-55-6	$0	$3,720
Disperse Red 11	0.0000	0.1390	2872-48-2	$0	$680.00
TA	0.0000	0.0660	100-21-0	$0	$88.32
Sulfur	0.0900	0.0000	7704-34-9	$17.28	$0
Sugar	0.0000	0.1420	57-50-1	$0	$87.00
Magnesium carbonate	0.0000	0.0870	546-93-0	$0	$76.28
Potassium chlorate	0.2600	0.2160	3811-04-9	$147.68	$135.30
Stearic acid	0.0063	0.0050	57-11-4	$11.10	$8.88
Sodium bicarbonate	0.2500	0.0340	144-55-8	$44.00	$0
Polyvinyl alcohol	0.0200	0.0200	9002-89-5	$0	$75.56
TOTAL				$6,444.06	$4,871.34
Components/Materials Added					
Starter patch					
Sugar			57-50-1		
Solvent Red 1			1229-55-6		
Disperse Red 11			2872-48-2		
TA			100-21-0		
Magnesium carbonate			546-93-0		
Components/Materials Eliminated					
Disperse Red 9			82-38-2		
Starter slug					
Starter cup					
Cardboard disc					
Sulfur			7704-34-9		

Notes:
(1) The weight fractions need not equal 1 because they reflect a granulated formula.
(2) The labor cost to produce one batch of current red smoke grenades is $4,375.14.
(3) The labor cost to produce one batch of new red smoke grenades is $3,624.19.
(*) weight to weight

The labor savings associated with manufacturing the new grenades, when subtracted from the cost of manufacturing the current grenades, results in a significant savings. The labor savings is a direct result of using starter patches rather than slugs. The use of starter patches during the current manufacturing process results in a significant cost savings. This cost savings should continue in the future, even if the manufacturing process undergoes change. If and when it is determined that there is an environmental cost, that cost would be added to keeping the current formula versus lowering or substantially lowering the costs of cleanup.

5.3 COST COMPARISON

Tables 9, 10, and 11 show the cost comparison of the materials used for reduced sulfur smoke grenades versus the sulfur fueled smoke grenades.

5.3.1 Cost Comparison for Violet M18

The production cost increase for a batch of violet M18s in the new configuration can be attributed to the increased cost of the reformulated smoke mixture and an increase in the number of grenades produced per batch (922 versus 883). Conversely, costs for the grenade bodies and fuzes are unchanged from the old formulation, and labor costs are actually decreased.

5.3.2 Cost Comparison for Red M18

Note that the difference of only $0.18 per item for the red M18 grenades is based on the unsuccessful pilot testing of the reconfigured rounds that failed to meet MILSPECS for smoke color. Any changes made during future attempts to reconfigure the rounds to meet PM-CCS standards will result in changes to the costs shown in Tables 9 and 11.

6.0 IMPLEMENTATION ISSUES

6.1 COST OBSERVATIONS

The two main factors affecting the cost of the grenades are, in order of importance, the cost of the labor to make the grenades and the cost of the dye.

6.1.1 Labor

The cost of labor in the current configuration is approximately $4,375.14 per approximately 800-lb batch of red or violet smoke grenades, or $4.95 per grenade. For the new starter patch configuration, the cost of labor is approximately $3,624.19 per batch, or $3.93 per grenade. The cost of labor is expected to be reduced by approximately 17.2% per 800-lb batch of grenades.

6.1.2 Dye

The cost of the dyes is expected to rise by approximately 333%. Previous buys were at $15/lb but current government buys are expected to be approximately $50/lb. Product searches on the Internet revealed foreign costs to be $8.25/lb (90% solvent dye); however, current laws require sources to "buy American," making it difficult to purchase from a foreign source directly (i.e., India, or China). These same laws will allow the purchase from a foreign source if it is determined that the price is 50% or greater. Prices of $50/lb versus $8.25/lb would meet that requirement and allow the purchase of foreign dye; however, it is currently unknown if the government will opt for the approach of buying dye from foreign sources to curb expenses.

6.1.2.1 <u>Contaminants</u>

There are concerns that the purchased dyes may contain contaminants such as heavy metals (e.g., lead, chromium VI, barium, mercury, and antimony). Contamination will be a concern in the quest to provide a less toxic smoke product. Based on emissions testing, some heavy metals exist either in the dyes, pyrotechnic mixtures, fuze, or the lead coating on and inside the grenade can itself . It appears that additional refining of the dyes to remove contaminants would be an appropriate strategy to undertake. The need to undertake additional dye refining will obviously add to the costs of the current dyes and any future dyes. However, if refining activities are completed at the production source, there could be significantly reduced costs, depending on the technology used here (for U.S.-acquired dyes) versus there (for foreign-acquired dyes). The Smoke and Dye IPT is expected to change the requirements for dye and other materials in the future to meet this requirement for all of the dyes used in the production of colored smokes. For additional emissions information, please refer to Appendix G from the Final Technical Report (see Reference 13).

It may also be worth noting that there are dyes with lower contaminant levels available for the food, textile, and cosmetics industries. The U.S. Food and Drug Administration (FDA) controls the certification of color additives (i.e., dyes) used in food, drugs, and cosmetic products. To avoid confusion in the use of color additives, the FDA created three categories of certifiable color additives: (1) Food, Drug, and Cosmetic (FD&C), (2) Drug & Cosmetic (D&C), and (3)

External Drug and Cosmetic (ED&C). Due to the expectation that the final smoke products may be inhaled, only the first two categories were examined by the Smoke and Dye IPT.

6.2 PERFORMANCE OBSERVATIONS

The substitution of a sugar-chlorate formulation smoke and less toxic dyes was successfully implemented for green and yellow M18 smoke grenades and for red, green, and yellow 40 mm projectiles. The red 40 mm smoke grenade was also successfully transitioned to these new materials. Similar changes to the red and violet M18 smoke grenades initially proved unsuccessful due to excessive burning of the dyes, resulting in failure of the items to meet MIL-STDs for signaling. Later, with funding provided by ESTCP, reconfiguration of the red and violet M18 smoke grenades based on the M90 LVOSS grenade, utilizing redesigned starter patches, proved more effective. These starter patches reduced the labor costs by approximately 17.2%. The LVOSS grenade was fitted with a new starter patch in order to control burning similar to that experienced with red and violet M18s. The patch slowed the starter mixture's contact with the smoke mix, allowing the temperature of the mixture to decrease and eliminating excessive flaming. This process was successful for both smokes; however, the transition to the red was not successful due to the coloration of the smoke being less red than desired.

6.3 SCALE-UP

The scale-up production should not have a significant effect on the production of red smoke grenades because, as part of the ESTCP plan, a full production run was made for red smoke grenades. The same applies for the production of violet smoke grenades; violet smoke grenades were simply not tested due to a lack of funding. Scale-up to previous production rates will introduce cost savings based on significant purchases of dye, approximately 24,800 lb of Disperse Red 11 if PBA goes to full production rate (250,000 of each color of the smoke grenades a year). These cost savings should increase even more significantly if the purchases of the violet and red dyes are done simultaneously because one of the dyes is the same (Disperse Red 11), and the Violet smoke grenade will use 113,150 lb of Disperse Red 11, plus the 24,800 lb will equal 137,950 lb of Disperse Red 11 purchased in 1 year. Even if PBA decides not to scale-up the production to the previous levels, the above amounts could be purchased based on the storage life of dye being approximately 3 years. But again, it will depend on PBA's decision on whether they want to purchase to this scale. It should also be noted there will be savings in labor and fewer rejects on the production line when PBA transitions to the starter patch configuration.

6.4 OTHER SIGNIFICANT OBSERVATIONS

Changes (e.g., starter patches and fill formulation modification) to the M83 grenade that would lengthen the burn time of the TA fill and eliminate the need for HC-zinc (HC), an irritant, were also suggested. Modifications to the M83 have not yet been demonstrated but are planned based on the success of the reconfigured M18 smoke grenades. In addition to utilizing starter patches, earlier studies have indicated that adding a small quantity of pentaerythritol to the M83's smoke mix will lengthen burn times and improve smoke cloud volume.

6.5 LESSONS LEARNED

The starter patch configuration will introduce labor savings (approximately 17.2% per 800-lb batch) to the production of all of the colored M18 smokes grenades.

There will also be fewer rejects on the production line using the starter patch configuration because the height of the smoke slugs is significantly reduced. In the past, the height of the smoke slugs sometimes caused the top slug to be knocked out of the grenade while in the production line.

It was also determined that the addition of TA (which alone creates a white smoke) was the cause of the light coloration of the new red smoke formulation resulting in PM-CCS determining that the new color failed to meet the MIL-STD requirements for the smoke produced. Recently a new dye (Palitol Black) was identified that "pulls" the white color out of the smoke. Follow-on work will be necessary to determine whether the addition of this new dye to the mixture or a new path forward will be necessary for transitioning red M18 smoke grenades to a less toxic dye mixture and replacing sulfur with the sugar-chlorate formulation.

6.6 END-USER/ORIGINAL EQUIPMENT MANUFACTURER (OEM) ISSUES

End users of this demonstration will be all units and installations that use the colored smoke grenades in their current formulation. As long as MILSPECS are met, the transition to the new formulation will be seamless. The products affected will be the violet M18 smoke that may transition to the replacement of the sulfur with sugar and the replacement of the dyes. It is also expected that the red M18 smoke grenade will transition from sulfur- to sugar-based fuels and, depending on the decisions of the Smoke and Dye IPT, will switch to a less toxic dye. In addition, based on this success, it is expected the other colored smoke grenades and the smoke pots will also be switched to the starter patches to decrease the cost in labor and the number of rejects occurring during production. The environmental impacts linked with potential contamination associated with use of these grenades will also be reduced once the transition has been completed.

6.7 APPROACHES TO REGULATORY COMPLIANCE AND ACCEPTANCE

Reconfiguration of the violet M18 smoke grenade was successful. Toxic dyes currently found in the rounds were replaced with less toxic dyes and sulfur was replaced with a sugar-chlorate smoke formulation. Pilot tests of the reconfigured rounds resulted in PM-CCS determining that the rounds met all MIL-STDs necessary for the round to be transitioned into use during training events. Because the new rounds are less toxic than the original smoke and dye formulations, transition from the old to the new configuration will result in less impact to the environment and increased health and safety for soldiers.

New rounds are in compliance with the regulatory drivers outlined in Section 1.3 of this report. No additional regulatory compliance and acceptance issues are anticipated based on the reconfiguration of these rounds.

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